

# **Westinghouse Fuel Cell Combined Cycle Systems**

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## **Introduction**

It is well known that the efficiency (voltage) of the solid oxide fuel cell (SOFC) should increase with increasing operating pressure. Further, it has long been postulated that because of the SOFCs high operating temperature, an SOFC operating at elevated pressure could function as the heat addition process in a Brayton cycle engine. This combined cycle would utilize the pressurized SOFC electrochemical engine as the topping cycle to a Brayton cycle gas turbine engine. Given that the SOFC can extract half of the fuel's heating value [LHV] as electricity, and assuming that the Brayton cycle engine can operate at 40% efficiency [LHV], then an overall cycle efficiency of 70% should be possible. This level of efficiency is better than that postulated for very large advanced combustion turbine plus steam turbine combined cycle systems, but without the complexity. In cogeneration applications, it is reasonable to expect that half of the waste heat from a Pressurized SOFC/Gas Turbine [PSOFC/GT] combined cycle system could be captured in process steam and hot water, thus yielding a fuel effectiveness of approximately 85%.

## **Objectives**

In order to make the PSOFC/GT system a commercial reality, satisfactory operation of the SOFC at elevated pressure must be verified, a pressurized SOFC generator module must be designed, built, and tested successfully, and the combined cycle configuration and parameter values must be optimized with respect to application and the cost of electricity. In addition, a prototype of the PSOFC/GT system must be demonstrated. In the following, progress toward making the PSOFC/GT a reality is described.

## **Approach**

For the past three years, Westinghouse and Ontario Hydro Technologies (OHT) have been collaborating on the investigation of SOFC performance at elevated pressure. Two pressurized test stations, each capable of accommodating one, two, or four tubular SOFCs, were designed by Westinghouse in conjunction with OHT, and subsequently fabricated, installed and operated by OHT. Test articles containing four air electrode supported (AES) SOFCs of 16 mm diameter by 500 mm active length have been tested at pressures up to 15 atmospheres. Several single AES cells of 22 mm diameter by 1500 mm active length have also been tested.

Work supported by Westinghouse and several North American utilities identified an integer MW power plant designed for grid support as the best market entry product for a distributed power generation application. The name SureCELL™ was devised to designate the PSOFC/GT power plants to be offered commercially in the year 2000. The top level design requirements established for SureCELL™ power plants are: natural gas fueled; net LHV efficiency > 60%; turndown ratio = 4:1; unattended operation; manned cold startup time < 8 hours; NO<sub>x</sub> emission < 5 ppmv; and noise level < 60 dBa @ 10 m. Conceptual designs were developed in response to these requirements using a case study approach and available turbomachinery.

## **Accomplishments**

Cell testing results from OHT corroborate theoretical estimates of the increase in cell voltage (at constant current) as a function of pressure. From Figure 1, it can be seen that at ten atmospheres pressure, cell voltage, hence cell efficiency, is about ten percent greater than that at one atmosphere. This voltage improvement is twice that available at three atmospheres, and half that predicted for thirty atmospheres. AES-SOFCs tested for 5000 hours at various pressures up to 15 atmospheres have shown no degradation or other deleterious effect. Endurance testing is presently in process. In addition, a pressurized bundle test facility and test article (circa 13 kWe) have been designed, and are in fabrication with startup expected in the first quarter of 1997.

In our SureCELL™ conceptual design effort, a search for available turbomachinery identified a two shaft combustion turbine of 1.4 MW capacity with a claimed efficiency of 43%. The first shaft functions only as a hot gas generator, with ac generated from an alternator coupled to the power turbine. High system efficiency is achieved through the use of two stages of intercooled compression, regenerative recuperation of the exhaust, and reheat for the power turbine. The compressor's turbine inlet pressure is nine atmospheres and the design point turbine inlet temperature matches the exhaust gas temperature available from the SOFC, 850 °C. Figure 2 shows schematically a cycle using this two-shaft turbine with a PSOFC module placed upstream of the compressor's turbine so that it could supplant the combustor in normal operation.

Using the design for the 100 kWe (atmospheric pressure) SOFC generator module now in manufacture as a building block (1152 cells, each 22 mm diameter by 1500 mm active length), a conceptual design was developed for a generator submodule using two such building blocks, each with an additional cell row (96 cells), in a common canister. An isometric view of this submodule is shown in Figure 3. The resulting submodule with 2496 tubular AES-SOFCs has a nominal capacity of 600 kW dc at nine atmospheres pressure. In order to supply the required mass flow to match the 1.4 MW turbine, three SOFC submodules are required, yielding 1.8 MW ac at the system design point. The three SOFC submodules are shown installed in a horizontal pressure vessel in Figure 4. The entire PSOFC/GT power system is shown configured for outdoor installation in Figure 5.

With reheat for the power turbine to achieve the design point value for turbine inlet temperature, the net system capacity is estimated at 3.3 MW, with a net electrical generating efficiency of 63%. If the system is augmented with additional SOFCs to supplant the power turbine's reheat combustor, then an efficiency level over 70% can be achieved at a power level of 5 MW. The performance of the SureCELL™ 3 and SureCELL™ 5 power plants is contrasted in Table 1.

## **Benefits**

Since the PSOFC/GT combined cycle can be configured to achieve these very high levels of efficiency at capacity levels two orders of magnitude smaller than non-fuel cell systems, the SureCELL™ PSOFC/GT is the ideal distributed power generator. Widely dispersed and located near load centers, SureCELL™ systems could contribute to a world wide reduction in carbon dioxide production because of their inherent efficiency. Using desulfurized fuel and with minimal fuel combustion, the SureCELL™ system would also produce significantly less NO<sub>x</sub> and SO<sub>x</sub> than non-fuel cell alternatives.

## **Future Activities**

Westinghouse is pursuing support from DOE, utilities, and other interested parties in order to demonstrate in the year 2000 a commercially prototypic SureCELL™ 3 MWe PSOFC/GT combined cycle power generation system with greater than 60% efficiency.

In the first quarter of next year, a pressurized bundle test facility will be operational at OHT. The first pressurized bundle test article will use 48 AES-SOFCs of 22 mm diameter by 1500 mm active length yielding a fuel cell stack capacity of approximately 13 kWe. Active testing of the first bundle test article will begin in the second quarter of 1997.

The first atmospheric pressure 100 kWe SOFC system is scheduled to undergo factory acceptance testing in the first quarter of next year with site installation and operation commencing within the first half of 1997. The fuel cell stack for this unit is half of the submodule envisaged as the basic building block for future SureCELL™ power plants.

## **Acknowledgments**

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Figure 1. Pressurized SOFC Performance

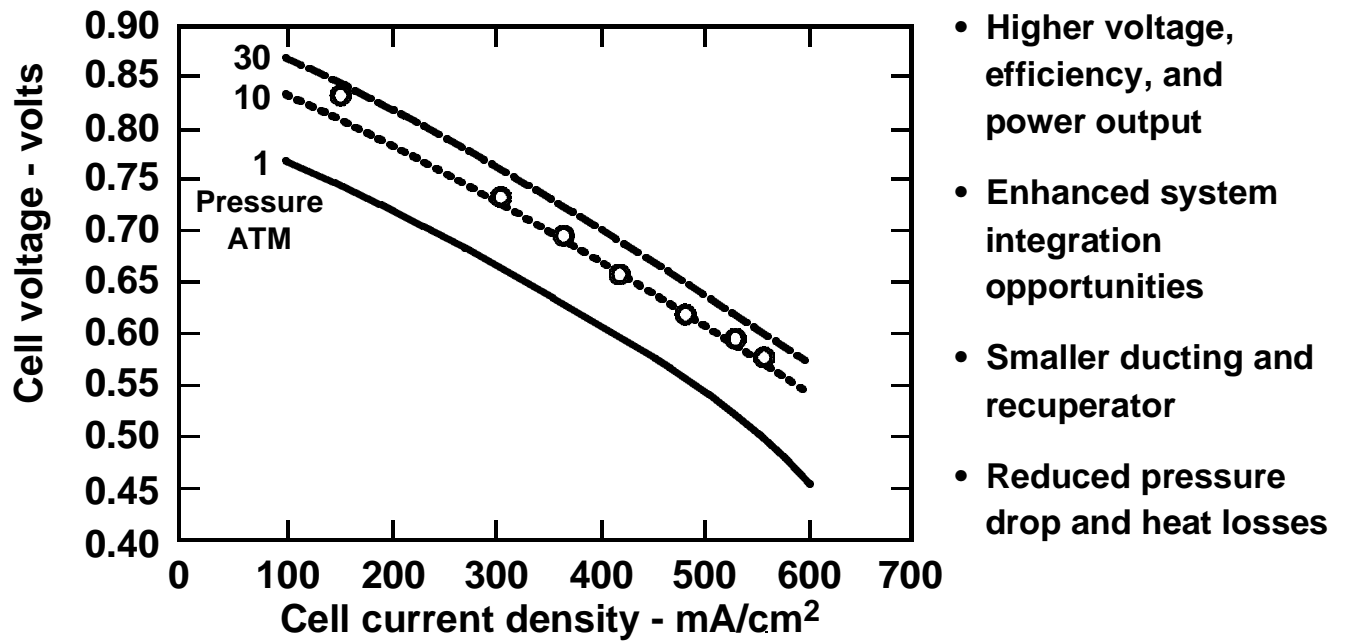


Figure 2. SureCELLä 3 MW Power Plant Process Flow Diagram

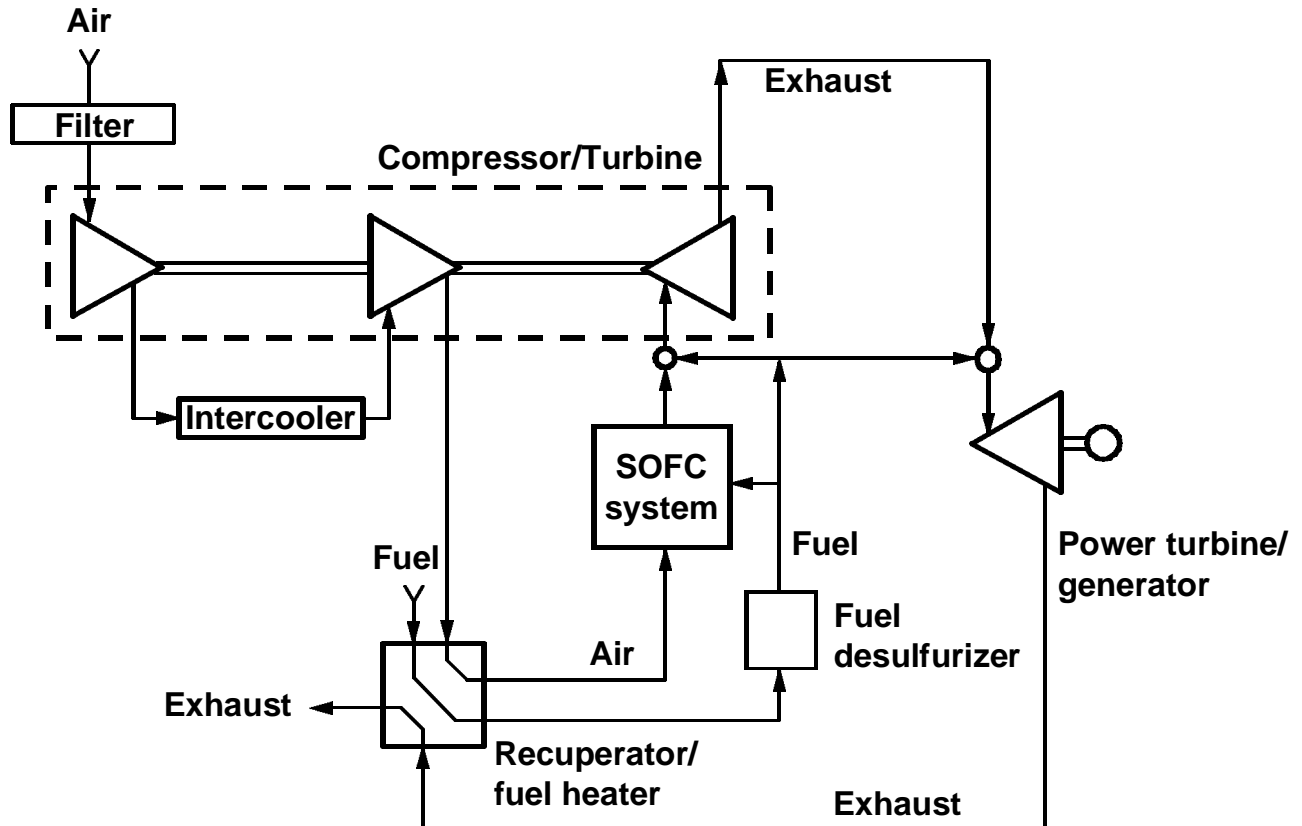
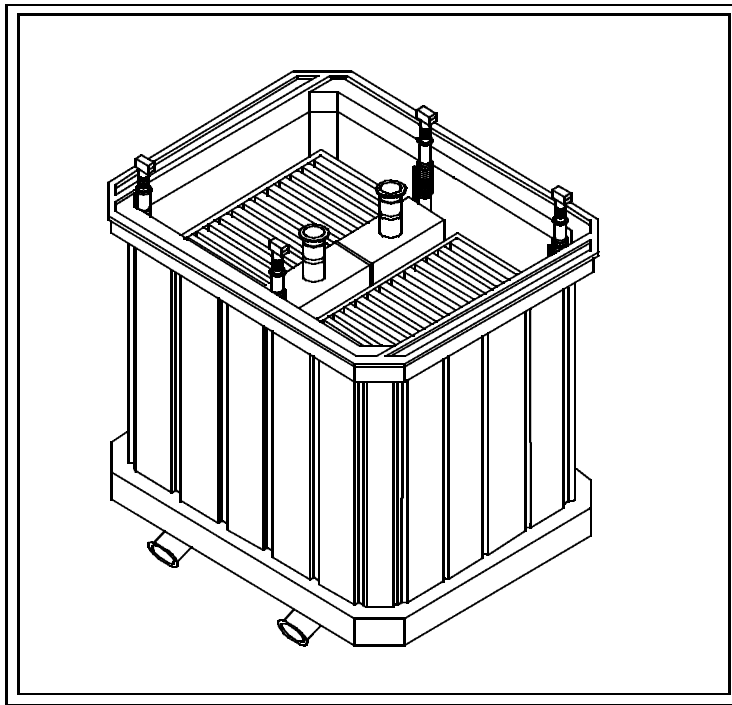
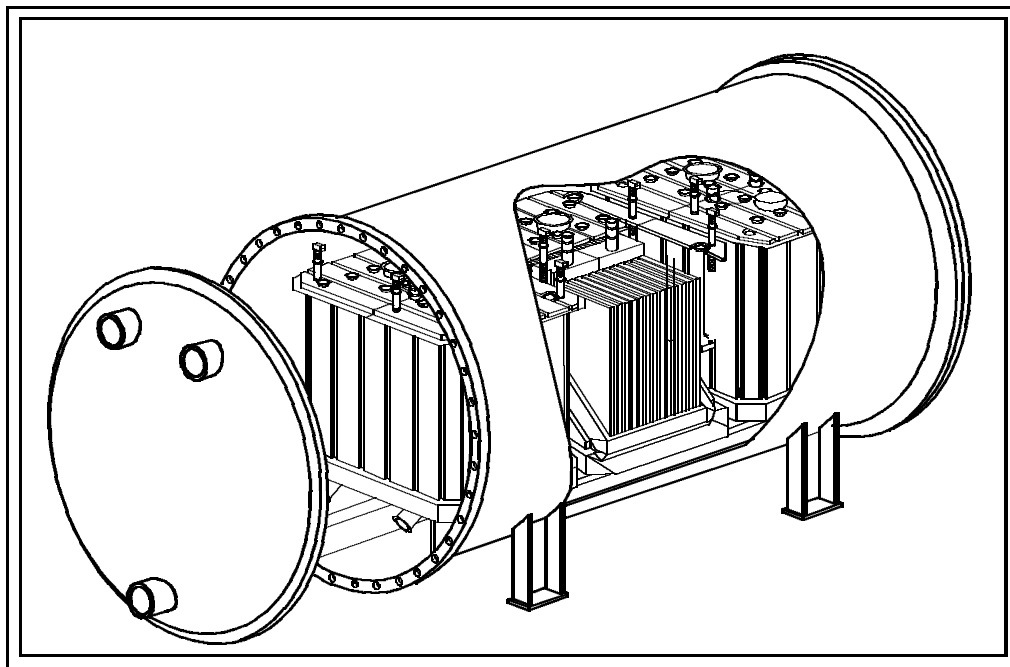


Figure 3. Pressurized SOFC Submodule



- 2.2 cm AES cell
- 150 cm active length
- 2496 cells
- Nominal dc power = 600 kW

Figure 4. Pressurized SOFC Submodule



- Diameter = 4.2 m
- Length = 9.3 m
- Nominal dc power = 1.8 MW

Figure 5. SureCELL™ 3 MW Power Plant

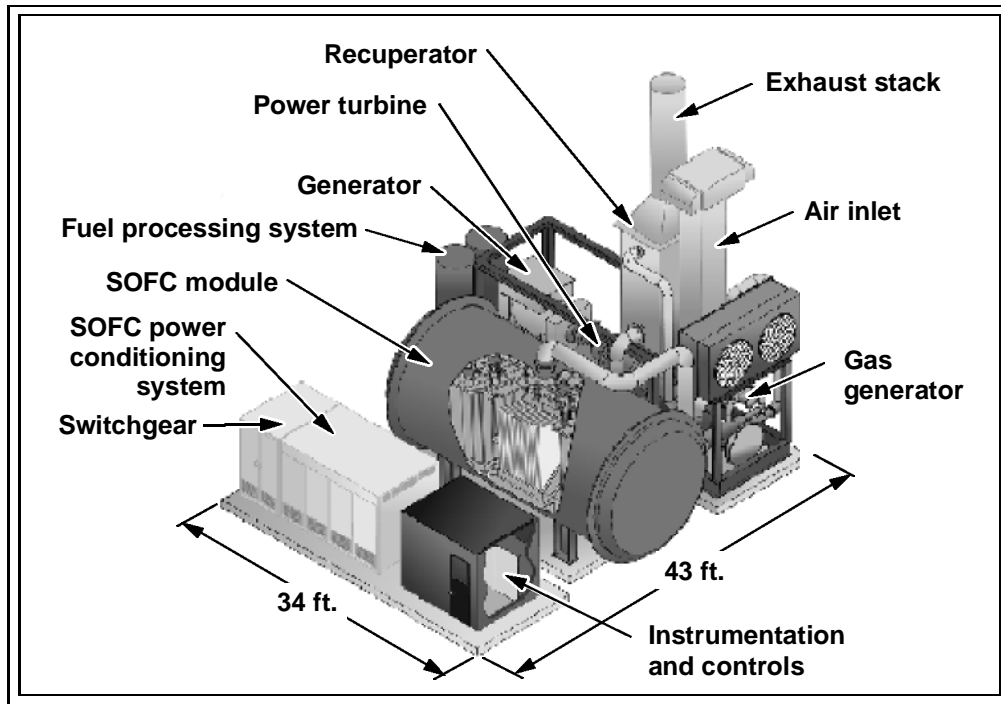


Table 1. SureCELL™ Performance Summary

	SureCELL™ 3	SureCELL™ 5
Rated Capacity, MW	3.3	5.2
Fuel	Natural Gas	Natural Gas
SOFC Net AC Power, MW	1.9	3.8
GT Net AC Power, MW	1.4	1.4
Heat Rate, BTU/kWh (LHV)	5375	4875
Plant Efficiency (LHV), %	63	70
Footprint, ft <sup>2</sup>	<2000	<2500